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Methods for energy analysis of residential buildings in Nordic countries

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ABSTRACT

To meet the goals of the directive 2010/31/EU on the energy performance of buildings, the building sector in Europe now faces a transition towards more energy efficient buildings. Research and development of new energy solutions and technology will be necessary for the transition and the importance of analyzing building energy performance increases. This paper aims to review and evaluate different methods that are commonly used to analyze energy performance in residential buildings in Nordic countries, primarily in Sweden, Norway and Finland. A short international review of regulations is also included. The goal is to find commonly used methods and possibilities for the future. The introduced methods are summarized, categorized and compared based on their advantages and disadvantages. Although the three Nordic countries have similar climate conditions and building traditions, the review shows relatively large variations in the definitions of energy performance for residential buildings, as well as variations in how measurements and calculations are used in the methods for energy performance analysis. In the conducted review, methods, or parts of methods, are also found to be used. The methods used to analyze energy performance are found to be more similar than the concepts of energy performance itself in the three countries. These aspects may be considered in further work to develop an international policy practice for energy performance of residential buildings in cold climate.

Contents

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1. Introduction

Buildings have a significant impact on the environment through resource and energy use, but also on human health and productivity. To meet the current building needs and reduce the impacts on future generations, the use of building materials, technologies and methods that promote environmental, economic and social sustainability throughout the buildings lifecycle will be required. Energy performance is one criteria used to assess sustainable buildings, which always has been important in cold climates as in the Nordic countries. To meet the goals in the directive 2010/31/EU [1] (EPBD recast) on the energy performance of buildings, the building sector in Europe now faces a transition towards more energy efficient buildings, such as low energy buildings and passive houses. By 2020, all new buildings should be nearly zero-energy buildings, the greenhouse gas emissions and energy consumption should be reduced by 20% and the share of renewable energy sources should be 20%. The requirement for building energy certifications in the original EPBD, 2002/91/EC [2], came into effect 2006 and could be used as a mean to reach these goals. Development and validation of new technology and energy solutions is necessary for the transition and as a part in this, the importance of analyzing building energy performance will increase. Building codes in many EU countries have started to reflect this, with bigger requirements on energy performance and its verification. For example, the German building code sets requirements on specific heat transmission loss in relation to the building envelope (*U*-values) and annual primary energy use [3]. There are no fixed numbers; the requirements are adapted to the building form factor, but also to the type of domestic hot water heating, and to the local climate. In the Danish building code, primary energy factors are applied to the energy performance requirement since 2006 and two classes of low energy buildings are introduced, with 50% and 25% stricter requirements [4]. Energy certifications have been implemented in Denmark since 1997 [5]. By Spanish experience, updates of the building energy requirements should however be well thought through. If the new requirements are not properly object oriented, the result could actually be a higher allowed energy demand [6]. Spain was however one of the first countries to set requirements on minimum contributions of solar energy for new buildings [7].

Earlier research by North Pass [8] presents a state-of-the-art review on local building regulations and standards currently used in some European countries. It shows that many of the Scandinavian countries put some sort of requirement on energy demand in their building codes and have started to develop specifications for low energy buildings. Specifications on low-energy buildings are also studied in Thullner's [9] comparative study on low-energy buildings in nine European countries. It shows that there are a large number of conflicting low-energy and passive-house building definitions existing in Europe today. The "passive house" technique was originally standardized in Germany, by the Passive House Institute (PHI) [10]. For this passive house definition, maximum permissible levels are set on specific space heat demand, specific primary energy demand (including household electricity) and air permeability at 50 Pa. The PHI passive house definition does not take primary energy into account. Concern is sometimes voiced against Passive houses, regarding air-tightness and restrictions on design. High air-tightness can result in problems with indoor air quality and moisture; and while thick walls, a small window area and a small form factor are beneficial for the energy efficiency, they can restrict the design of the building. High air-tightness however does not cause problems, unless the ventilation is inadequate. The mechanical ventilation with heat recovery often used in passive houses often also result in better indoor air quality. By compensating for the energy efficiency in other ways, it is also possible to build passive houses in many different designs, even with normal walls, a large window area or a big form factor. It is significant to consider the energy-aspect already in the design process to fulfill the goal for energy efficient buildings. The CEPHEUS project [11] has tested and proven the viability of the Passive House concept at a European level. One conclusion form the project is that the PHI passive house definition needs to be adapted to different climate conditions. The recommendation to adapt the definition to different climate conditions could be expanded to different conditions in general, for example availability of different energy source. The large number of conflicting passive-house definitions today can be seen as a result of this.

Building energy efficiency is also becoming an important factor in countries worldwide. A study on regulatory standards related to building energy conservation in China shows that the country only introduced requirements on building energy in the late 80's but has later quickly developed requirements for its wide range of different climates and for different types of buildings. The obstacle, and something to be considered in Europe as well, is to raise public awareness Wang et al. [12]. Concern has also been raised that the transition of the EPBD to national legislations is going slower than expected in Europe and if there are enough monitoring and enforcements to ensure compliance [13]. None of the above studies are however focused on the evaluation methods used to analyze energy performance. The aim of this paper is to review and compare methods that are commonly used to analyze energy performance in residential buildings in the Nordic countries Sweden, Norway and Finland. The goal is to find commonly used methods and possibilities for the future. Since Nordic countries have a dominant cold climate during the year, the methods are more focused on analyzing heating than cooling energy. Advantages and disadvantages of the method are discussed, as well as shared methods or parts of methods used. In this context, the overview of comparative methods presented illustrates the complexity in comparing the results.

2. Method

The review is based on a literature study on the newest regulations, standards and energy evaluation methods in the three Nordic countries as well as personal consultations and communication with national experts. First, experts were contacted and a survey was sent out to gather knowledge within the project. Second, the building regulations on energy efficiency and passive house specifications in each country were summarized, to illustrate the range between the currently legislated level of building energy performance and existing "best practice" as a foundation for the review. Third, methods were studied based on the contributions from experts and project members; methods defined in standards, regulations or specifications, methods developed in different programs, and alternative methods. They were summarized and compared based on what measurements they cover, the type of method, if it is based on measurements or calculations, components in the calculation or measurements, and the use of weather data. In Finland and Norway, the review mostly covers methods defined in standards and regulations and a larger investigation is necessary to evaluate methods used in practice in these countries. Only energy performance was considered in this review, related building properties such as human comfort and moisture for example were not studied.

3. Review

A summary of building code and passive house regulations/specifications in Sweden, Norway and Finland is presented in the

Table 1
National building code regulations and passive house specifications.

		Sweden			Norway			Finland			
		Building code	Passive house 2009	Passive house 2012	Building code Alt 1. Alt 2		Passive house	Building code 2010	Building code 2012	Passive house VTT	Passive house RIL
Level of requirement	Regulation	×	–	–	×	×	×	×	×	–	–
	Specification	–	×	×		–	–	–	–	×	×
Requirement	*U*-values [W/m^2 K]	× [a]	× [b]	× [b]	×	× [c]	×	–	×	–	×
	Thermal heat loss [W/K]	–	–	–	–	–	–	×	×	–	–
	Heat load [W/m^2]	–	×	×	–	–	–	–	–	–	–
	Space heating energy [kW h/m^2]	–	–	–	–	–	×	–	–	×	×
	Net energy [kWh/m^2]	–	–	–	–	×	–	–	–	–	–
	Supplied energy [kWh/m^2]	×	–	×	–	–	–	–	–	–	–
	Total energy [kWh/m^2]	–	–	×	–	–	–	–	×	–	–
	Primary energy [kWh/m^2]	–	–	–	–	–	–	–	–	×	×
	Air tightness [h^{-1}][l/sm^2][m^3/hm^2]	–	×	×	×	× [c]	×	×	×	×	×
	Heat recovery in ventilation [%]	–	–	–	×	–	×	×	×	–	–
	Window area per floor area [%]	–	–	–	×	–	–	×	×	–	–
Area	Heated floor area, external	–	–	–	–	–	–	×	–	×	× [d]
	Heated floor area, internal [e]	× [f]	× [g]	× [g]	× [h]	× [h]	× [h]	–	× [d]	–	–
Climate Zones	None	–	–	–	×	×	× [i]	–	–	–	–
	Three	×	×	×	–	–	–	–	–	×	×
	Four	–	–	–	–	–	–	×	×	–	–
Included posts in net, delivered or total energy	Space heating	×	–	×	–	×	–	–	×	×	×
	Hot water	×	–	×	–	×	–	–	×	×	×
	Cooling	×	–	×	–	×	–	–	×	×	×
	Ventilation and auxiliary energy [j]	×	–	×	–	×	–	–	×	×	×
	Lighting	×	–	×	–	×	–	–	×	×	×
	Household electricity	–	–	–	–	×	–	–	×	×	×
Weighting Factors used	None	× [k]	–	–	× [l]	× [l]	× [m]	×	–	–	–
	National	–	×	×	–	–	–	–	×	–	–
	Primary	–	–	–	–	–	–	–	–	×	×

[a] Presented as an average heat transfer coefficient.
[b] Only for windows.
[c] Minimum requirements.
[d] Spaces heated over 17 °C.
[e] Internal walls included.
[f] Spaces heated over 10 °C, not included internal garage area.
[g] Spaces heated over 10 °C, including internal garage area.
[h] All spaces with installed heating system.
[i] Continuous climate scale.
[j] Energy for ventilation heating, pumps, fans, control and heat recovery.
[k] Different requirements for electric and non-electric heating. Local production of renewable energy is not included.
[l] $>60\%$ of the net heat energy should come from other sources than direct acting electricity and fossil fuels for buildings larger than 500 m^2, $>40\%$ for buildings smaller than 500 m^2.
[m] Less than the total net energy minus half of the net energy for domestic hot water should come from fossil fuels or electricity.

first section below and in Table 1. A summary of methods used for energy performance analysis in the three countries is presented in the second section and in Table 2 together with Table 3.

3.1. National regulations and specifications

This section presents a summary of building code and passive house regulations/specifications in the three countries. Regulations are official and mandatory, while specifications are more unofficial guidelines. Two versions of building codes are presented for Finland since it was updated during the work of this review and the direction of its development contributed to the conclusions. Two versions of the Swedish passive house specification are also presented for the same reason.

3.1.1. Sweden

3.1.1.1. Building code regulation. The 2011 Swedish building code today, BBR 19 [14], is a system-focused regulation, less focused on individual building parts or components and more on the building as a total energy using system. The requirements in the building code are on *U*-values, presented as an average heat transfer coefficient, and supplied energy. The maximum permissible heat transfer coefficient is 0.4 W/m^2 K. The requirements on supplied energy are presented in Table 4. Household electricity and energy produced by local solar panels is not included. Three climate zones with different requirements on supplied energy are defined, as shown in Fig. 1. The area used for normalization of the supplied

Table 2
Energy certification in the three countries (*C*: calculation, *V*: standard values, *E*: standard equations, *M*:measurements).

		Sweden	Norway Alt. 1	Alt. 2	Finland
Energy performance	Supplied energy	×[a]	–	×[b]	–
	Net energy	–	–	–	×[a]
	Individual measures	–	×	–	–
Cover	Energy performance	×	×	×	×
	CO_2-indicator	–	–	–	–
	Technical data	×	–	–	×
	Suggestions for improvements	×	×	×	×[c]
	Measured energy	–	×[d]	×[d]	–
	Certification of technical installations	×[e]	×	×	–
	Radon	×	–	–	–
Based on	Calculations	×[f]	×[g]	×[g]	×[h]
	Measurements	×[i]	×[i]	×[i]	×[j]
Calculation method	According to building code	×	×	×	×
	Weather data	Local	The capital	The capital	Jyväskylä
Measurement method	Energy production efficiency	–	V	V	V/M
	Correction for normal year	×[k]	×[l]	×[l]	×[m]
	Duration	1 year	3 years	3 years	–
	Solid fuels	C	–	–	C
	Hot water	E	–	–	E
	Building electricity	V	–	–	E[n]
	Electric heating	M[o]	–	–	V
	Energy factors	–	×	×	–
	Separating energy between buildings	×[p]	–	–	–

[a] kWh/m^2 year.
[b] kWh/year.
[c] Only for separately issued certifications.
[d] For 3 years.
[e] Verification of ventilation system.
[f] For new buildings and alternatively for existing buildings.
[g] Standard method.
[h] For new buildings and existing buildings with less than 6 dwellings.
[i] For existing buildings.
[j] For existing buildings with more than 6 dwellings.
[k] SMHI energy index method or degree day method.
[l] According to NS–EN 15603.
[m] Using weather data for a normal year in Jyväskylä.
[n] Calculated according to the building code.
[o] Tabulated values and standard equations used to separate out household- and building electricity.
[p] Measurements, weighting by calculated energy or by energy signature method.

energy is based on a definition of heated net floor area. To take energy sources into account in the supplied energy, there are different requirements for buildings heated with electricity than for buildings heated by energy-sources with lower exergy.

3.1.1.2. Passive house specification. The 2009 Swedish passive house specification [15] was developed by FEBY, a forum formed by institutes, collages and others, in consensus with the Swedish energy agency and Swedish National Board of Housing, Building and Planning. The specification focuses on building energy performance in the form of heat load. The requirements in the specification are based on *U*-values for windows, heat load and air tightness. The specification also includes recommendations on heat recovery efficiency, supplied energy and total energy (based on supplied energy and national energy factors). The maximum permissible air tightness at 50 Pa is 0.3 l/sm^2, maximum permissible *U*-value for windows is 0.9 W/m^2 K and minimum recommended heat recovery efficiency 70%. The requirements on heat load and recommendations for total- and supplied energy are presented in Table 5. The energy factors are 2 for electricity, 1 for district heating and biofuels and 0 for sun and wind energy. Energy produced by sun panels on the site is not included and deductions can be made for sun and internal heat gains in the heat load. The normalization of the energy demand is conducted based on the same area as in the building code, but the area in the passive house specification also includes internal garage area. The same climate zones as in the building code are used to set the heat load requirements and energy recommendations.

The passive house specification was updated in Jan 2012 [16]. In the new specification focuses on heat load and supplied energy. The requirements are based on *U*-values for windows, heat load, air tightness, supplied energy or total energy based on national energy factors. The maximum permissible air tightness at 50 Pa is changed to 0.3 l/sm^2 or 0.5 l/sm^2 for small buildings with an enclosing area to heated floor are ratio bigger then 1.7. The maximum permissible *U*-value for windows is changed to 0.8 W/m^2 K. The changed requirements on heat load and on energy are presented in Table 6. The garage area is no longer included in the normalization area and deductions can no longer be made for sun and internal heat gains. The energy factors are changed to 2.5 for electricity, 0.8 for district heating, 0.4 for district cooling and 1 for other energy sources.

3.1.2. Norway

3.1.2.1. Building code regulation. The Norwegian building code [17] focuses either on individual measures or on a more energy system-focused evaluation. The individual requirements are flexible and the thermal heat loss coefficient is a step towards a more integrated system approach to energy evaluation in buildings. There are two alternative requirements in the building code. The first one, “Alternative 1” in Table 7, is on energy measures. It puts requirements on *U*-values and other measures to ensure energy

Table 3
Methods for energy performance analysis (M: measured, C: calculated, V: standard values or equations, S: survey).

		Sweden			Norway		Finland	Other
		Building code	Passive house	SVEBY	Building code	Passive house	Building code[a]	Energy Signature
Cover	Heat losses	× [b]	× [b]	–	× [b]	× [b]	–	× [bd]
	Heat load	–	× [e]	–	–	–	× [c]	×
	Net energy	–	–	–	×	×	×	–
	Supplied energy	×	–	×	× [f]	× [f]	×	×
	Primary energy	–	–	–	×	×	–	–
	Energy from different energy carriers	–	–	–	×	×	–	–
	CO_2-emissions	–	–	–	×	×	–	–
	Energy cost	–	–	–	×	×	–	–
Methods	Monthly stationary method	× [g]	×	×	× [d]	× [d]	×	–
	Simplified hourly dynamic calculation	–	–	–	×	×	–	–
	Detailed dynamic simulation programs	×	–	–	×	×	–	–
Based on	Calculations	× [h]	×	–	× [d]	× [d]	×	–
	Measurements	× [i]	× [d]	× [d]	× [i]	× [i]	×	×
Calculated energy	Standard equations/values	×	–	–	× [j]	× [j]	× [k]	–
	Measured input values	–	×	–	× [l]	× [l]	× [m]	–
Measured energy	Energy production efficiency	–	–	–	V	V	V	–
	Correction for normal year	× [n]	–	× [o]	× [p]	× [p]	–	×
	Duration	1 year	–	2 years	3 years	3 years	–	10 periods[q]
	Solid fuels	C	–	C	–	–	C	–
	Exported energy	–	–	–	× [r]	× [r]	–	–
	Hot water	M[s]	M/C	C	–	–	M/C	M[t]
	Building electricity	–	× [u]	M[v]/V	–	–	M/V	–
	Household energy	M[s]	S/M	M[v]/V	–	–	–	–
	Electric heating	–	–	M	–	–	–	–
	Energy factors	–	–	–	×	×	–	–
	Internal loads account	×	–	–	–	–	× [x]	×
	Sun energy	–	× [y]	–	–	–	–	×
	Number of residents	–	S	–	–	–	–	–
	Indoor temperature	–	M/S	–	–	–	–	×
	Separating energy between buildings	–	–	M	–	–	–	–
Weather data	Local climate	×	×	–	–	×	×	–
	Capital climate	–	–	–	×	–	–	–

[a] 2010.
[b] Presented as average heat transfer coefficient.
[c] Presented as thermal heat loss.
[d] Standard method.
[e] Also include cooling, hot water and electricity.
[f] Weighted.
[g] Degree days.
[h] For new buildings.
[i] For existing buildings.
[j] For building code compliance.
[k] If no measurements are available.
[l] For predicting real energy.
[m] Voluntary.
[n] Degree days or energy index.
[o] Degree days or power signature.
[p] According to NS–EN 15603.
[q] At least 7 days long each.
[r] Deductible.
[s] Alternative.
[t] Energy use during summer.
[u] Recommendation.
[v] If the energy amounts to more than 3 kWh/m^2.
[x] Only if significant.
[y] Values from SMHI, measurements or data from the normal year.

Table 4
Requirements on supplied energy for the three climate zones in the Swedish building code [14].

	I	II	III
Heated with electricity[a]	95	75	55
Other heating methods	130	110	90

[a] Installed electricity power more than 10 W/m^2.

efficiency. The requirements in this first alternative can be deviated from as long as the thermal heat loss coefficient does not increase. “Alternative 2” in Table 7 is on an energy framework and puts requirements on net energy. Minimum requirements for *U*-values always have to be fulfilled. The area used for normalization of the net energy is the heated area of the net usable floor area [9]. To take energy sources into account, special requirements are made on the amount of renewable energy use.

3.1.2.2. Passive house regulation. The energy performance definition in the Norwegian passive house regulation [18] focuses on energy for space heating. The requirements in the regulation on space heating energy, *U*-values and overall heat transfer coefficient are presented in Tables 8 and 9. The maximum permissible air tightness

is 0.6 h^{-1} and minimum permissible heat recovery efficiency is 80%. The requirements on space heating are adapted for colder climates than the capital and for buildings smaller than 250 m^2. The area used for normalization of the energy demand is the same as in the national building code. Cooling is not allowed in residential buildings. To take energy sources into account, the regulation states requirements on the amount of renewable energy use.

3.1.3. Finland

3.1.3.1. Building code regulation. The 2010 Finnish building code [19] is solely focused on individual building components, but a new building code was launched in July 2012 [20]. It is a development towards a more system-focused regulation with requirements on energy demand. The requirements in the 2010 Finnish buildings code are based on *U*-values, presented as total thermal heat loss, air tightness, heat recovery efficiency and window area. For air tightness at 50 Pa, 2 h^{-1} is used as the reference value and 4 h^{-1} for the actual building, if nothing else is known. The minimum permissible heat recovery efficiency is 45% and the maximum permissible window area is 15% of the floor area. Two requirements are added in the new regulation: total heat transfer coefficient and total energy – *E*-numbers – where national energy factors are applied to the supplied energy. The energy factor for electricity is 1.7, for district heating 0.7, fossil fuels 1, district cooling 0.4 and renewable energy 0.5. The unit for the requirement on air tightness is also changed to m^3/hm^2, which means a stricter requirement for buildings with smaller enclosing area than internal volume—a small form factor. The requirements for energy and *U*-values in both regulations are presented in Table 10. The gross floor area is used for normalization in the 2010 building code [21]. In the new regulation, the normalization is done by the heated net gross floor area. The country is divided into four climate zones, presented in Fig. 2. Weather data from the buildings climate zone is used to dimension the installed power, but weather data from climate zone 1 is used when demonstrating compliance with the total energy requirements in the new building code.

Fig. 1. Climate zones in the Swedish building code [14].

3.1.3.2. Passive house specification. There are two passive house specifications in Finland today. One is based on recommendations from VTT—Technical research center of Finland [22]. The VTT passive house specification focuses both on specifics and overall energy performance and the requirements are on air tightness, space heating energy and primary energy (based on primary energy factors). The maximum permissible air tightness at 50 Pa is 0.6 h^{-1}. The energy requirements are presented in Table 11. The primary energy factors are 1.1 for oil, 0.4 for district heating and 0.2 for wood based fuels. The area used for normalization is the gross floor area. The specification defines three climate zones, presented in Fig. 3, with different energy requirements. [8] the second passive energy building specifications in Finland is a guidebook from RIL—Finnish association of civil engineers [23]. The RIL passive house specification includes requirements both on the envelope in the form of *U*-values, space heating energy, primary energy and air tightness. The maximum permissible air tightness at 50 Pa is 0.6 h^{-1} and the minimum permissible heat recovery efficiency is 75%. The requirements on *U*-values and energy are presented in Table 12. The area used for normalization of the energy is the heated gross floor area. The RIL specification is based on three climate zones, with different energy requirements.[9] The *U*-value and energy requirements are also adopted for single-family or multi-family buildings. [8] the passive house concept is however still under development in Finland. New independent passive house specification-alternatives are still being created and the existing ones are expected to be adapted more to the new building code regulations in the near future. Only time can tell which one will become general, or most commonly used.

3.1.3.3. Comparison of building regulations and specifications. Analyzing and comparing energy performance is important for the development towards more energy efficient buildings, but the definition of building energy performance can be very different from country to country. This makes it difficult to compare energy efficiency across national borders and also constitutes a problem for the building industry when developing energy efficient buildings. By Spanish experience, any changes in the energy regulations should however be well thought through, as to not result in a higher allowed energy demand. When constructing building energy performance requirements, the system boundary first must be decided. Should only the buildings net energy use be considered, or should also

Table 5
Requirements on heat load and recommendations for total- and supplied energy for the three climate zones in the 2009 Swedish passive house specification [15].

		I	II	III
Heat load [W/m^2]	Residential and commercial buildings	12	11	10
	One or two family residential buildings[a]	14	13	12
Total energy [kW h/m^2]		68	64	60
Supplied energy [kW h/m^2]	Buildings heated by electricity[b]	34	32	30
	Buildings heated by other energy sources	58	54	50

[a] <200 m^2/dwelling.
[b] Installed electricity power more than 10 W/m^2.

Table 6
Requirements on heat load and energy for the three climate zones in the 2012 Swedish passive house specification [16].

		I	II	III
Heat load [W/m^2]	Residential buildings[a]	17	16	15
Total energy [kW h/m^2]		73	68	63
Supplied energy [kW h/m^2]	Buildings heated only by electricity[b]	29	27	25
	Buildings heated by only other energy types[c]	58	54	50

[a] Buildings smaller than 400 m^2 gets an additional 5 kW h/m^2.
[b] Buildings smaller than 400 m^2 gets an additional 2 kWh/m^2.
[c] Buildings smaller than 400 m^2 gets an additional 5 kWh/m^2.

Table 7
Requirements for *U*-values, air tightness, heat recovery, window area and net energy demand in the Norwegian building code [17].

		Alternative 1	Alternative 2
U-values [W/m^2 K]	Walls	0.18	0.22[a]
	Roof	0.13	0.18[a]
	Floor	0.15	0.18[a]
	Windows and doors	1.2	1.6[a]
	Thermal bridges, small buildings[b]	0.03	–
	Thermal bridges, other buildings	0.06	–
Air tightness at 50 Pa [h^{-1}]	Small buildings[b]	2.5	3[a]
	Other buildings	1.5	3[a]
Heat recovery [%]		80[c]	–
Window and door area[d] [%]		20	x[e]
Net energy	Small buildings	–	120+1600/m^2
demand [kW h/m^2]	Other buildings	–	115

[a] Minimum requirements, also for alternative 1.
[b] Single-family buildings, town houses and detached houses.
[c] Annual mean temperature efficiency.
[d] Fraction of floor area.
[e] *U*-values for windows and doors multiplied by their fraction of floor area should be less than 0.24.

Table 8
Requirements on space heating [kW h/m^2] in the Norwegian passive house regulation [18].

	A_{fl}[a] <250 m^2	A_{fl}[a] >250 m^2
θ_{ym}[b] >6.3 °C	$15+5.4\times((250-A_{fl})/100)$	15
θ_{ym}[b] <6.3 °C	$15+5.4\times((250-A_{fl})/100)+(2.1+0.59\times((250-A_{fl})/100))\times(6.3-\theta_{ym})$	$15+2.1\times(6.3-\theta_{ym})$

[a] Heated area of the net usable floor area.
[b] Yearly average temperature.

Table 9
Requirements on *U*-values and overall heat transfer coefficient in the Norwegian passive house regulation [18].

U-values [W/m^2 K]	Walls	0.15
	Roof	0.13
	Floor	0.15
	Windows	0.8
	Doors	0.8
	Thermal bridges	0.03
Overall heat transfer coefficient [W/m^2 K]	$A<100$ m^2	0.6
	$100<A>250$	0.55
	$250<A$	0.5

distribution losses, energy production losses or energy sources be taken into account? The definition of building energy performance in the Swedish building code is based on supplied energy. Energy sources are taken into account by having stricter requirements on electrically heated buildings and deducting any energy produced by sun panels on the site. Energy losses from energy production inside, but not outside, the building are included in supplied energy, which makes it an inconsistent measurement of building energy performance. Household electricity is also not included in the Swedish definition of supplied energy, as an attempt to minimize influences from user behavior. The definition of building energy performance in the Norwegian building code and the new Finnish building code is based on net energy, which is a more consistent definition of building energy performance than supplied energy. In Norway, requirements are made on the percentage of renewable energy used, as a way to take the energy sources into account. Requirements for renewable energy sources also exist in other European countries today, Spain for example. The new regulation in Finland considers the biggest system of the three, with the use of national energy factors. These factors are an attempt to take both primary energy and energy sources into account. Requirements on primary energy are also used in Germany and Denmark, as discussed in the introduction. As seen above, energy performance is defined differently in the building codes of all three countries today. A general trend towards a more system-focused evaluation of energy performance is however visible, which can also be seen in the changes between the 2010 and 2012 Finnish building code. The building codes in all three countries are trying to take both the energy efficiency of the building into account, minimizing the influences of user behavior in different ways, and of the larger energy system. Having an inconsistent system boundary can give unexpected results, not reflecting either the buildings or the systems energy efficiency. A large system is difficult to predict and do not accurately reflect the

Table 10
Requirements on total energy – *E*-numbers – and *U*-values in the two Finnish building codes [19,20].

			2010	2012
Total energy [kW h/brm^2] (*E*-numbers)	Single-family buildings	$A < 120$ m^2	–	204
		120 m^2 $> A <$ 150 m^2	–	$372–1.4 \times A_{netto}$
		150 m^2 $> A <$ 600 m^2	–	$173–0.07 \times A_{netto}$
		$A >$ 600 m^2	–	130
	Townhouses or terraced houses		–	150
	Apartment buildings		–	130
U-values[W/m^2 K]	Walls		0.17[a]/0.26[b]	0.17[a]/0.26[b]
	Roof		0.09[a]/0.14[b]	0.09[a]/0.14[b]
	Floor, crawl space		0.17[a]/0.26[b]	0.17[a]/0.26[b]
	Floor, ground based		0.16[a]/24[b]	0.16[a]/24[b]
	Windows and doors		1[a]/1.4[b]	1[a]/1.4[b]

[a] Heated areas.
[b] Partially heated areas.

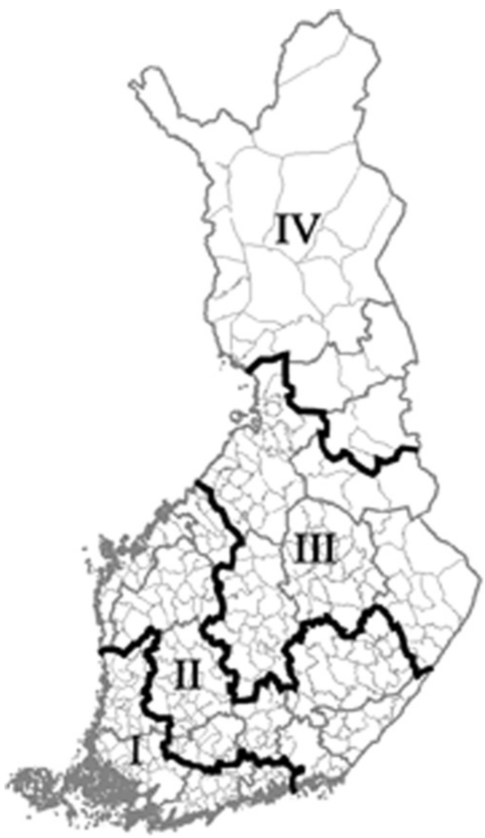

Fig. 2. Climate zones in the Finnish building code [20].

Table 11
Requirements on space heating and primary energy for the three climate zones in the Finnish VTT passive house specification [8].

	South	Middle	Lapland
Space heating [kW h/m^2]	20	25	30
Primary energy [kW h/m^2]	130	135	140

specific buildings energy performance. Having a small system boundary could on the other hand result in a high primary energy use if the building is not also adapted to the energy system. To get an optimized building energy performance; taking net energy, primary energy and energy sources into account; more than one requirement might be necessary. There is a need for a discussion on how building energy performance should be defined and what it aims to measure, to create an international policy for energy performance.

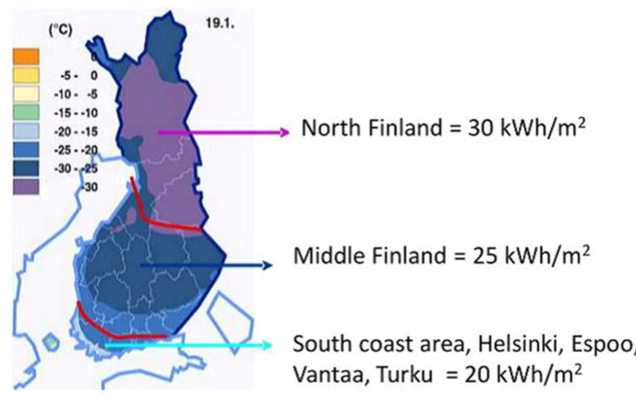

Fig. 3. Climate zones in the Finnish VTT passive house specification [8].

Table 12
Requirements on *U*-values, space heating and primary energy in the Finnish RIL passive house specification [8].

		Single-family buildings	Multi-family buildings
U-values [W/m^2 K]	Walls	0.08–0.10	0.12
	Roof	0.07	0.08
	Floor, crawl space	0.08	0.10
	Floor, ground based	0.10	0.10
	Windows	0.7/0.8 [a]	0.8
	Doors	0.5	0.5
Space heating [kW h/m^2]	Ordinary winter use	10–20	10–15
	Peak load	25	20
Primary energy [kW h/m^2]		140	135

[a] Fixed or openable window.

The definition of building energy performance in the new Swedish passive house specification is based on both power and energy. The use of heat load is one way to minimize influences from user behavior on energy performance, supplied and total energy is used to take the bigger energy system into account. In Norway, the building energy performance is based on space heating. This is one way to exclude user behavior influences from domestic hot water and electricity, but in Norway there are no requirements on energy use for other purposes than space heating. In Finland, two alternative passive house specifications set requirements on space heating energy and primary energy. This is an attempt to make a total assessment of the buildings energy

Table 13
Input data for indoor temperature and internal heat gains in building codes and passive house specifications [8,16,18,36].

	Sweden			Norway		Finland	
	Building code	Passive house 2009	Passive house 2012	Building code	Passive house	Building code 2010/ 2012	Passive house (both)
Indoor temperature	22 °C	20 °C	21 °C	21 °C, 19 °C night set-back	21°C, 19 °C night set-back	21 °C	21 °C
Internal heat gains	Adaptions from EN 13790	4 W/m^2	4 W/m^2	5 W/m^2	5 W/m^2	8 kWh/brm^2[a] 17 kWh/brm^2[b]	–

[a] For single family buildings.
[b] For other residential buildings.

performance, both as a separate unit and as a part of the larger energy system. Since the requirements in the three countries passive house specifications are even more different than the building codes, it is difficult to compare the definitions of energy performance for passive houses. It can be determined that the passive house specifications are influenced by the national building codes to some degree. If these become more similar, so will probably the passive house specifications, especially if they are defined in more official specifications. It would also be interesting to investigate if an official regulation promotes a wider use. All of the passive house definitions carry some trait of the PHI passive house specification: requirements on space heating in both Finland and Norway, primary energy in Finland and Sweden (total energy) and requirements on air tightness in all three countries. A common denominator, separating them from the PHI definition, is that they all are adapted to the colder climate in the Nordic in some way.

Unified ways to handle parameters affecting the energy performance and input data is also important to achieve a comparable measure of building energy performance. As an example, the standard input data for indoor temperature and internal heat gains used in the building codes and passive house specifications, in Table 13, are different in the three countries today. In Table 1, it can also be noted that the floor area used for normalization also is defined somewhat differently in all countries, but has developed towards becoming more similar. Different units are used for air tightness in the three countries. Different solutions are also used to adapt the energy performance requirements to the climate, either by introducing climate zones, by having a continuous scale of requirement depending in the outside temperature, or by using the same specified climate to verify all buildings in the country. A requirement independent of the climate can also be used, as is the case in the 2010 Finnish building code. Some form of adaption to the climate is however necessary to create fair and feasible requirements. In Germany, the requirements are also adapted to the buildings form factor, as to not limit the architectural freedom. This is another aspect to be considered in the energy performance requirements. In the three studied countries, the requirements are also adapted to different building types today, although this review only includes residential buildings. The use of input data and parameters that affect the energy performance also need to be considered in the discussion on the definition of building energy performance. A Swedish study [24] on quality classification of recorded data on building energy show that very few buildings meet the requirements for the best quality rating in Sweden today. The most important parameter influencing the uncertainty of the energy data was found to be the method used for the analysis. These methods will be studied further in the next section.

3.2. Methods for energy performance analysis

This section presents a summary of methods used for energy performance analysis in the three countries. Methods for energy certification are presented in Table 2, methods used in building codes and passive house regulations/specifications, together with other methods are presented in Table 3.

3.2.1. Sweden

3.2.1.1. Energy performance certification. The present regulation on energy performance certification in Sweden was introduced 2006 [25]. The energy performance certification applies to all new and existing residential buildings when sold or rented, where new buildings are buildings in the projection phase and existing buildings are buildings under operation. The certification is valid for 10 years and includes building energy performance, technical data, possible energy saving measures, and any requirements on ventilation system verification or radon assessment. The calculation method is described in a specific regulation from the Swedish National Board of Housing, Building and Planning [26], with a separate collection of recommendations in Regulations on energy performance certification with comments [27]. Additionally, guidelines on how to separate energy measurements, both between buildings and within the building can be found in The Swedish standard institute handbook on energy certification [28]. Supplied energy is calculated according to the national building regulations or alternatively measured for existing buildings. The annual volume use of any solid fuels is calculated to kWh. A correction should be done when several buildings are measured with one meter. The energy performance is presented with a heating character and is compared to reference values. The reference values are energy requirement for new buildings and a building type specific interval for energy performance.

3.2.1.2. Building code. There are no calculation- or measurement-methods defined in the Swedish building code, but the method is described in standard SIS-EN ISO 13790:2004 [29]. The national energy certification can also be used. Recommendations can also be found in a handbook from the Swedish national board of housing, building and planning [30], which refers to several other ISO standards and also the SVEBY program (see below). The requirements on supplied energy can be verified either by calculation or by measurements. In the planning phase, a simulation program is normally used to calculate the energy performance. Hand calculation methods can be used for buildings with less complexity. For operated buildings, the supplied energy is measured and summed up during one year, and then corrected for the normal year. Solid fuels are transformed to energy by calculation. Household energy should be measured separately and if corrections are to be made for deviations from normal domestic hot water use, a separate meter for this is also needed.

3.2.1.3. Passive house. Instructions for the Swedish method to analyze energy performance of passive houses are published both in the specification by FEBY [15], and in the related report [31]. Only the specification is updated for the 2012 regulation so far, not the method description. Since no detailed description exists of the method for the new regulation, the presented method here is the one corresponding to the 2009 specification. Measurements of maximum power and air tightness must be conducted and energy use should be available for monthly readings, separately for household electricity, space heating, auxiliary energy and energy for domestic hot water preparation. The standard method for verification is by measurements, if this is not possible, calculations using as much measured input data as possible can also be used. The buildings thermal heat loss coefficient [W/K] is calculated using measured and calculated data for the heating season and then used to determine the maximum power use. Domestic hot water preparation should be measured. When it is measured with the same meter as the heating, the power for domestic hot water preparation can be separated out by a standard calculation method. The household electricity use can be determined by survey or measurements. Standard values can be used for the available heating power from the sun, or measurements at the local site. The heating power from people is based on information from a survey. The indoor temperature is determined by measurement with simple alcohol thermometers or by survey. The outdoor temperature is taken from standard values or from conducted measurements at the local site. A follow up of the calculated values is required for verification [9]. This method is used in practice and analyzed in an article by Molin et al. [32], among others.

3.2.1.4. SVEBY program. The SVEBY program is a development program run by the construction and real estate industry. It presents a complimentary, non-compulsory method to analyze supplied energy and verify building code compliance in Sweden [33]. The SVEBY program proposes that separate measurements should be done for each energy carrier, during at least two years, and corrected for the normal year. Delivered district heating and gas can be measured with ordinary billing meters. The amount of oil, bio-fuels and other fuels used should be measured. The supplied energy for space heating and domestic hot water preparation shall be measured with separate meters for each energy carrier. The energy use for domestic hot water preparation is calculated from measured hot water volume and subtracted from the measured total heating energy to get the energy for space heating. When calculations are used, corrections for normal domestic hot water usage are made by user data from SVEBY. Residential electricity should be measured separated from the electricity used for space heating. A sub meter for household electricity should be installed if it is measured with the same meter and amounts to more than 3 kWh/m^2. If several buildings have the same energy supply, sub-meters should be used. Results from the use of this method for the energy analysis of a number of real buildings can be found in [34].

3.2.2. Norway

3.2.2.1. Energy performance certification. The energy performance certification in Norway was introduced 2009 [35]. It is applicable to new as well as existing residential buildings when sold or rented. The certification is valid for 10 years. It presents a record of the energy performance in the form of a heating character, which is compared to reference values, and a heating character based on delivered energy. It also includes possible energy saving measures, certification of any larger technical installations, and measured energy for three years for existing buildings. The certification is based on the evaluation method according to NS 3031 [36] and standardized values from the building code, but evaluates supplied energy instead of net energy. The supplied energy is presented for each energy carrier. There are three ways of evaluation: simple evaluation, detailed evaluation and evaluation by an expert. Evaluation by an expert can be done by monthly calculations or imported from dynamic calculations in a simulation program. A “simple evaluation” only requires input data of building type, building year, BRA, and heating method. The energy performance is then calculated from standard values. The energy performance is presented on a scale between A and G is used, where C represents the current building code, and a heating character between green and red.

3.2.2.2. Building code. The calculation method referred to in the Norwegian building code is described in the Norwegian standard NS 3031 [36]. It refers to several other standards and is also used to evaluate passive house requirements and for energy certification. A monthly stationary calculation method, a simplified hourly dynamic method or detailed dynamic simulations can be used. In addition to net energy and air-tightness, a heat loss budget (*U*-values), overall supplied energy and divided to each energy carrier, primary energy, energy cost and CO_2-emissions should also be reported. Standardized input values are used to calculate the net energy when validating building code compliance. If the goal is to calculate the expected energy use, real input values are used. The supplied energy is calculated based on tabulated values for system efficiencies, or determined by measuring the supply from different energy carriers. Measured energy can be used if it covers a 3 year-period or if the data is corrected for a normal year. Exported energy from the building can be deducted. Primary energy, CO_2-emissions and energy cost is calculated by multiplying the supplied energy of the different energy carriers by a respective factor. Weather data from the capital is used. This method is tested with different simulation tools in an article by Haase et al. [37].

3.2.2.3. Passive house. The standard NS 3031 [36] is referred to for calculation methods. Local climate is used. A follow up in the form of measured air-tightness is required [9].

3.2.3. Finland

3.2.3.1. Energy performance certification. The law on energy performance certification in Finland was introduced 2008 [38]. The calculation method is described in a regulation from Finland’s environmental administration [39]. The certification is applicable for all new and at the sale or renting of existing buildings. The certification is in most cases valid 10 years and includes energy performance and technical data. Certificates issued separately also include energy saving measures. The assessment is based on calculations, except for existing buildings with more than 6 dwellings when it is based on actual energy use. The net energy use is calculated according to the national building code [21], and corrected for the normal year. The supplied energy is measured and the buildings net energy is calculated based on standard or measured values for the annual efficiency of the energy production. For solid fuels, the net energy is calculated from the net calorific value. Weather data from Jyväskylä – in the middle of Finland – is used. The energy performance is presented on a scale between A and G is used, where class D is equivalent to the 2008 building code. It is likely that this certification method will be adapted to the new building code regulation in the near future.

3.2.3.2. Building code. The 2010 Finnish building code includes a calculation method for net energy, supplied energy and heating power [21]. The supplied energy is calculated from the total energy use, based on standard values for the annual efficiency of energy production inside the building. A monthly balance method, partly based on the calculation method presented in the standard SFF-EN 13790 [29], is used, which refers to several other national standards. The total energy is based on net energy and does not include energy production losses. Standard values for heat losses are included in the heating power. Energy for solid fuels is calculated using the net calorific value and the amount of fuel used. The energy for domestic hot water preparation is calculated from the hot water volume used or based on circulation flow. Standard values can be used for energy use for domestic hot water preparation and building appliances if measurements cannot be done. The energy for electricity includes energy for appliances, heating and cooling. The calculation method in the 2012 building code is not yet fully developed, only drafts exist, but the new building code includes more requirements for measurements. New buildings should be equipped with measuring devices to provide information of the use of different energy sources.

3.2.3.3. Passive house. No follow up is required, but air tightness measurement is strongly recommended for both the VTT and the RIL passive house specification [9]. Results from the use of the VTT passive house verification method in practice can be found in Nieminen et al. article [40].

3.2.4. Other

3.2.4.1. Energy signature. The energy signature is a general method, a good description and analysis of it can be found in Hammarsten [41]. It is an established method for evaluating the energy performance of a building in terms of the overall heat loss coefficient. The analysis is conducted on measured supplied energy and corresponding outdoor temperatures collected from at least one heating season, with approximately ten measuring periods, corrected for the normal year. The supplied energy, generally on monthly or weekly basis, is plotted against mean outside temperature. From this analysis, the thermal heat loss coefficient is calculated from the slope or gradient of the equation. The supplied energy during the summer period is approximated to correspond to the energy for domestic hot water preparation [28]. The energy signature method is best suited for buildings with a small internal heat load and when the heating is strongly dependent on the outside temperature. The method is therefore less suitable for buildings with low energy use [42]. Low energy buildings are also more affected by solar radiation and have a shorter heating season, which makes the curve shorter and harder to interpret. Buildings with a high time constant need a longer period of measurements [31]. The method is tested and analyzed in practice in an article by Sjögren et al. [43], among others.

3.3. Comparison of methods for energy performance analysis

Energy performance analysis is an important aspect to ensure results from the energy performance requirements. It also plays a part in increasing the awareness of building energy performance and creating a foundation to enforce the requirements. As discussed in the introduction, awareness and enforcements have been found to be crucial for implementing building energy performance requirements. Methods to analyze building energy performance can be based on calculations or measurements, with a range of combinations in-between. Calculations need to be used to predict energy performance of a building, but is sometimes also used to verify building energy performance. Calculations and standard values do not reflect the actual energy use, but measured energy performance and input data on the other hand need to be normalized for normal year and user behavior.

Energy certifications have been adopted in European countries, based on the EPBD directive 2002/91/EC, since 2006. They are created with the same purpose, but the methods used are largely based on the countries building codes and therefore different. This is also the case in the studied countries, see Table 2. The energy certifications in Norway are based on calculation as a standard method, but have an additional requirement on measured energy for existing buildings. These calculations do not always reflect the specific buildings energy performance very well, since the alternative of a "simple evaluation" often is used. The energy certifications in Sweden and Finland can also be based on measurements for existing buildings, which could introduce unwanted impacts from user behavior. Generally, energy performance in new buildings is verified by calculation in the three countries, which questions if the certifications of new buildings reflect their real energy performance. For existing buildings, verification is sometimes done with measurements, which could create influences from user behavior that are difficult to interpret.

A monthly stationary method is used for building code compliance in all three countries. As for the energy certifications, calculations can always be used for new buildings and measurements can also be used for existing buildings in Sweden and Finland. When using a calculation method, the input data can either be measured or taken from standard values/equations. The calculation methods in Norway and Finland can be based on measured input parameters, whereas standard values or equations are used in Sweden. The measurement methods all use different techniques to normalize the data for a normal year and user behavior. The review supports the possibility to use the international standard ISO 13790 as a foundation for a comparable measurement of energy performance, since it is used in the methods to determine building code compliance in all three countries, but the use of the standard differs. Overall, it seems that the methods used to verify building energy performance for building code compliance are more similar than the concepts of energy performance itself in the three countries. If a uniform definition of energy performance existed, it would then be possible to compare energy performance across national borders with only a few adaptions of the methods.

Some form of measurement is required in all three countries passive house specifications; only air tightness measurements in Norway and Finland, but also measurements on energy use in Sweden. In Norway, the method for energy performance analysis of passive houses is the same as for determining building code compliance, which facilitates comparisons between passive houses and "standard" houses. In Sweden, the standard method for energy performance analysis of passive houses in Sweden is based on measurements and also use measured input values in the calculation method. The SVEBY and Energy signature method also use measurements to verify energy performance, although the energy signature method is more challenging for low energy buildings. The methods based on measurements generally put bigger requirements on separate and more accurate measurements. Although the methods for energy certification and verification of building code compliance are similar in the three countries, they generally allow use of very basic measurements of energy, sometimes measuring several buildings, and standard values or equations to determine energy performance. Thus, if the analysis of energy performance is based on measurements, more detailed measurements might be necessary to make objective comparisons possible.

4. Conclusions

Although the three Nordic countries have similar climate conditions and building tradition, the study shows that there exist relatively large variations in the definitions of energy performance for residential buildings and the handling of parameters related to it, such as normalization area and climate zones. The different definitions of energy performance make it difficult to compare the outcome of the measurement and calculation methods for analysis of energy performance. The definitions of energy performance for passive houses in the three countries are even more different than the definitions in the building codes. This work shows that a discussion on how building energy performance should be defined and what it aims to measure is needed to create an international policy for energy performance and important aspects of this discussion are pointed out.

Same analyzing methods, or parts of methods, are found in several countries. The methods used to analyze energy performance are more similar than the concepts of energy performance itself in Sweden, Norway and Finland. If a uniform definition of energy performance existed, it would be possible to compare energy performance across national borders with only small adaptions of the methods. Energy performance of new buildings is usually verified by calculation and existing buildings by measurements. If the energy performance analysis is based on measurements, more detailed measurements than required in the building codes today are necessary to make comparisons possible, separating energy posts and replacing standard values.

These aspects may be considered in further work to develop a more accurate and easily comparable policy to evaluate energy performance for residential buildings in cold climate. The presented work will be continued by investigating actual building energy performance outcome, by applying the Finnish, Norwegian and Swedish building codes to analyze a number of simulated reference buildings.

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Glossary

Energy need: Heating energy, electricity, internal energy and utilized solar radiation. No thermal losses included.;

Net energy: Energy (transmitted–retransmitted) from all energy systems, including the internal energy system losses. Net energy demand: calculated. Net energy use: measured.;

Supplied energy: Energy (supplied–resupplied) to all energy systems, this also includes losses from internal energy production. Locally produced energy is not included.;

Delivered energy: Also include distribution losses from external energy production.;

Total energy: Calculated from supplied/net energy using national energy factors (country specific).;

Primary energy: Also includes losses external energy production. Calculated form supplied/net energy using primary energy factors (from definition of primary energy).;

Thermal heat loss: Include envelope, air leakage and ventilation losses. [W/K];

Heat transfer coefficient: Include envelope losses. [W/m^2 K];

Heat load: Space heating energy and energy for domestic hot water preparation. [W];

Form factor: The ratio between the buildings enclosing area and internal volume..